# Land degradation monitoring in Sahelian Africa from both NDVI and rainfall data

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## ABSTRACT

The African Sahel has been a very controversial region in the climatic change debate during the last decades. From the studies that announced a dramatic advance of the desert in the 1970s [Lamprey 1975] and lead to the first conference about desertification [Nairobi, 1977] to the hopeful articles assuming a global recovery from the great droughts of the 70s and 80s [Prince et al., 1998; Hermann et al., 2005], many works have been carried out about this region. The studies of recent years are often characterized by their emphasis in the analysis of climatic fluctuations, specifically inter-annual and inter-decadal variations, as it is necessary to avoid misinterpretations related to climatic variability. Even if some authors have noticed a recovery as a result of increased rainfall since the mid 90s, the rainfall level of the 50s and 60s has never been reached again. It is not clear if a true climatic change is happening nowadays in the region, leading to degradation and desertification as a consequence of carry over effects from precedent droughts and reduced rainfall or if the changes observed are principally human-induced. Thus, two main variables are the most responsible of the observed changes in the last decades: climatic variability, related primarily to inter-annual and inter-decadal rainfall variability, and the demographic boom. Obviously, discriminate between climatic and human induced land degradation/improvement in a regional or global scale is an important matter that should be treated carefully. Following Evans et al. (2004) and Wessels et al. (2007) we have developed a method using the residuals of the NDVI-Rainfall relationship to retrieve the vegetation response in function of rainfall, so that climatic variability is cleaned off and human degradation is localized. The only remaining question is that the carry-over effects of precedent years are not taken into consideration and as a consequence detected trends cannot be only attributed to human factors. The evolution of Rain Use Efficiency RUE, the ratio of net primary production and rainfall, is also used here, as some authors claimed from observed RUE trends during the period 1982-2002 that degradation occurred in large areas of the Sahel, and we wanted to test this assumption. The studied region is depicted at figure 1.

The data used as a proxy of vegetation seasonal activity are taken from the GIMMS NDVI database, which is corrected for residual sensor degradation and sensor inter-calibration differences, effects of changing solar zenith and viewing angles, volcanic aerosols, atmospheric water vapor and cloud cover [Tucker et al., 2005]. The spatial resolution of this database is 8 km and it covers the period from 1981 to 2006 on a bi-weekly basis. The data used as rainfall is the CRU 2.1 rainfall product [Mitchell et al., 2005]. This product is based on the interpolation from in-situ measurements and it offers a good spatial resolution (0,5º); some problems can be found in highlands and very vegetated areas, that do not correspond to our study region. It covers the period from 1901-2002 (recently expanded) on a monthly basis. The GIMMS NDVI data have been re-sampled to match the CRU Rainfall at the same spatial and temporal resolutions.

The analysis of land condition degradation/improvement is based on the response of vegetation to rainfall. If the response of vegetation to the same amount of rainfall has significantly decreased with time we will consider that degradation has taken place, on the other hand, if the vegetation response has significantly increased we will deduce an improvement of land condition. The relationship between vegetation and rainfall is supposed to be linear. In fact, in very vegetated areas like tropical forest in the Guinean climate regions there is a saturation effect of rainfall that leads to a logarithmic function in the observed NDVI-rainfall relationship. We have tested both NDVI-Rainfall and NDVI-Log$_e$Rainfall relationships for the whole region; our results show that linear NDVI-Rainfall relationship is more adequate when annual mean rainfall is less than 600-700 mm/year; above this value the logarithmic relationship may be more suitable, Nicholson fixed the limit in 1000 mm/year [Nicholson et al., 1990]. Finally, we have chosen the linear relationship for the entire region, as the final results do not change significantly. The NDVI-Rainfall relationship is modeled on a pixel by pixel basis. The annual maximum NDVI is chosen as a proxy of vegetation productivity, because the accumulated NDVI for the growing period must take into consideration too much factors related to its position, time and length of the growing season [Evans et al., 2004], and this can lead to misleading results. Furthermore, we consider that accumulated NDVI is a measure of availability rather than a measure of vegetation productivity. As the heterogeneity of the region should lead to a number of optimum accumulations periods, several correlations are tested for each pixel with varying lags (time to reach the NDVI max) and periods of accumulated rainfall. Finally, the residuals of the NDVI-Rainfall relationship are calculated and regressed with time. For comparison purpose, the evolution of annual Rain Use Efficiency is also calculated as the ratio ΔNDVI/Rainfall during the period 1982-2002. As a final point we have tried to quantify the “memory” of vegetation to study the carry over effects during the two decades studied. Rainfall is weighted by a rainfall memory index to take into consideration the rainfall of precedent years. A different memory will be attributed to each pixel.

The analysis of residuals shows a net trend to recovery (Fig 1), seemingly as a consequence of increased rainfall from the mid 90s. Regions of Tchad and the Central Plateau of Burkina Faso present a clear tendency to improvement, because of increased rainfall and sustainable development practices [Hermann et al. 2005; Reij et al.,2005].

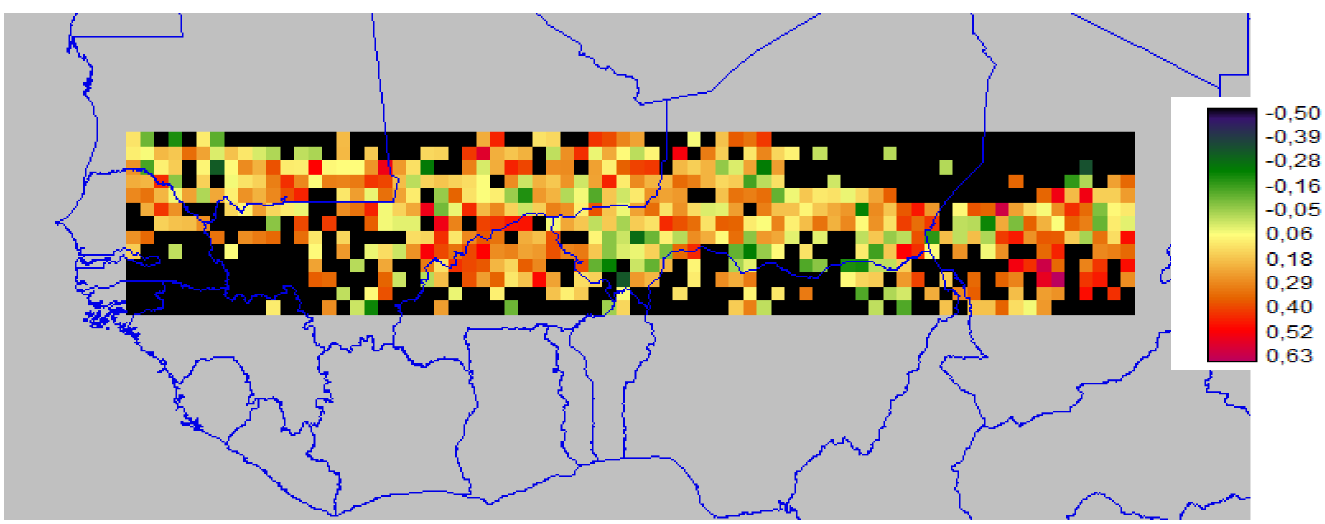


Fig 1. Correlation (Kendall) of residuals with time during the period 1982-2002. Black points had no significant correlation NDVI-Rainfall.

However the RUE evolution does not show this positive trend and even displays a negative trend in many regions. Our studies leads to the conclusion that negative correlation between rainfall and RUE is significantly strong so that it seems logical that RUE trend could be negative as the rainfall increased during the second half of the studied period causing the RUE to fall at the end of the time series. The studies we have carried out separating the whole period in two parts defend this hypothesis.

To take into consideration the carryover effects of precedent years we have studied the memory of rainfall. We have weighted the annual rainfall by a memory index and we have founded strong differences in patterns between the regions that showed an improvement in the residuals method and the regions that showed degradation. In general, it seems that improved regions have a long memory and degraded regions do not show any memory. The interpretation could be that the improvement trend has a strong climatic component during the studied period and on the other hand the degradation trend has a strong human component.

In conclusion, it appears that degradations have been observed only in restricted areas in the Sahel region during the period 1982-2002; for the whole region, a global pattern of recovery is accepted as a result of increased rainfall since the mid 90s. Degradation during this period is exclusively human- induced so that we can say that there was no climatic degradation. This does not mean a return to the good conditions of 60s and 70s. An analysis of an extended time series (which is not possible by means of NDVI because of the lack of satellite information before the 80s) could probably inverse the positive trend, so the present perspectives are not necessarily optimistic.

The residuals method is an interesting approach to follow the evolution of land condition and distinguish human-induced degraded regions from inter-annual climatic variations. This method should be helped by phenological analyses and memory analyses to try to understand the carryover effects.

## REFERENCES

Evans J., Geerken R. (2004), Discriminate between climate and human-induced dryland degradation. *Journal of Arid Environments, 57*, 535-554.

Hermann S., Anyamba A.,Tucker C.J., 2005, Recents trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change, 15*, 394-404.

Lamprey H.F., 1975. Report on the desert encroachment reconnaissance in northern Sudan.21 October to 10 November 1975.UNESCO/UNEP, Paris/Nairobi; republished in Desertification Control Bulletin, *17*, 1-7.

Mitchell T.-D., Jones P.-J., 2005, An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatogy, 25*, 693–712.

Nicholson S. Davenport M., Malo A.R.,1990, A comparison of the vegetation response to rainfall in the Sahel and East Africa, using Normalized Difference Vegetation Index from NOAA AVHRR, *Climatic Change, 17*, 209-241.

Prince S.D., Brown E., Kravitz L.L., 1998, Evidences from rain uses efficiencies does not indicate extensive Sahelian desertification. *Global Change Biology*, *4*, 359-374.

Reij C., Tappan G., Belemvire A., 2005,Changing land management practices and vegetation on the Central Plateau of Burkina Faso (1968–2002), *Journal of Arid Environments*, *63*, 642–659.

Tucker C.J., Pinzon J.E., Brown M.E., Slayback D.A.,Pak E.W., Mahoney R., Vermote E.F., El Saleous N., 2005, An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. *Internation Journal of Remote Sensing*, *26*, 4485-4498.

Wessels K.J., Prince S.D.,Malherbe J., Small J., Frost ,P.E.,Vanzyl D., 2007, Can human-induced land degradation be distinguished from rainfall variability? A case study in South Africa. *Journal of Arid Environments*, 67, 271-297.

Wiegand T., Snyman H.A., Kellner ,K.,Paruelo J.M, 2004, Do grasslands have a memory: Modeling phytomass production of a semiarid South African Grassland. *Ecosystems*, *7*, 243-258